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PCCR Based Wheelchair Control System

Abstract

Quadriplegia is an extremely serious disease. Due to the impaired function of patients' limbs, it is difficult for them to move freely by a wheelchair. This dilemma has become a huge obstacle to the rehabilitation of the disabled, and meanwhile added extra burden to society. To improve the quality of their lives, our team designs a vision-controlled automatic wheelchair based on the pupil center and cornea reflection (PCCR) technique. By constructing a multi-sensor real-time intelligent control system, the wheelchair realizes eye-controlled movements and other auxiliary functions such as emergency communication and rollover alarm. Through continuous optimization of multiple versions, a more intelligent, highly reliable, and low-cost wheelchair is manufactured.

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I. Introduction

According to the National Spinal Cord Injury Statistical Center (NSCISC), there are 240,000–337,000 people in the U.S. living with spinal cord injury (SCI), a serious type of physical trauma, and 47% of them are quadriplegic [1]. Compared with the average lifetime cost $428,000 of a 25-year paraplegic patient, the cost of a quadriplegic is up to $1,350,000 because of the special care for the paralysis of both upper and lower limbs. However, traditional wheelchairs could not satisfy quadriplegics' basic needs to control movements without a one-to-one nursing assistant. Our team focuses on designing an automatic wheelchair for the unfortunate.

It should be noted how we make use of a handful of *signal generators and receivers* on quadriplegic patients

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to give the control instructions while obtaining environmental information. Behavioral studies conclude that nearly 83.0% of the factors that affect communication come from vision. Thereupon, we envision whether the control can be achieved through eyes. Eye tracking, as a method to detect the presence, attention and focus, is a current hotspot in visual research [2], [3]. Through analyzing the visual behaviors, we can obtain the implied mental activities for further applications.

The eye tracker, a powerful input device in a host of visually-mediated applications, records the characteristics of human eye movements when processing visual information. Generally, there are four methods for estimation, i.e., electro-oculography, iris contact lens/search coil method, photo/video-oculography, and pupil center and cornea reflection (PCCR) technique [4]. Although the contact methods developed since the 1950s can achieve very high measurement accuracy, external objects are required to touch the susceptible parts of the human body and partly limit the human movements. Currently, the non-contact eye tracker designed by the PCCR technique is widely used, which mainly depends on the reflection of the pupil, the iris-sclera boundary, or the cornea to the proximal light source. Moreover, real-time eye movements could be easily tracked and analyzed bolstered by the increasing computing power. Hence, thanks to the pioneering technology, a fully automatic wheelchair for the handicapped is formed. Our main contributions can be listed as follow:

- A monocular algorithm to improve recognition accuracy is proposed.
- The whole wheelchair system, from sampling to the signal processing, and from the power supply to the mechanical structure, is implemented.
- The control logic on iterative versions through multiple clinical trials is optimized.

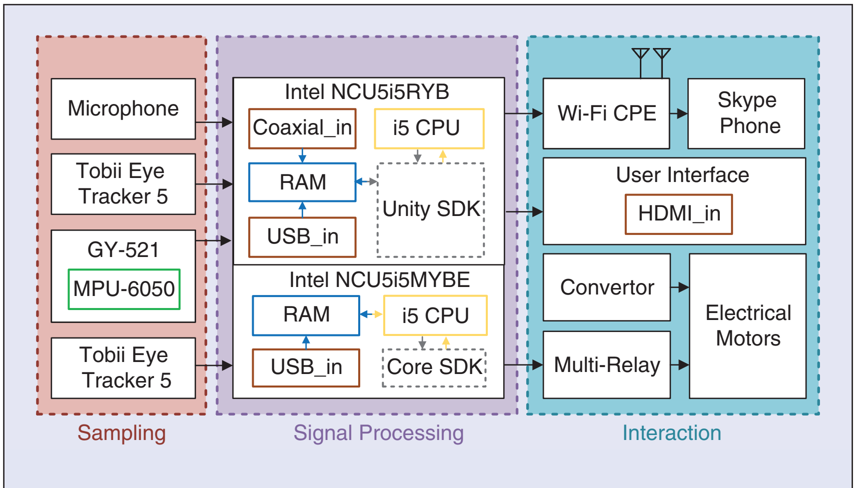

Figure 1. System overview of the PCCR based wheelchair.

The remainder of this article is organized as follows. Section II illustrates the system overview. Section III introduces the background on the core technology PCCR and relative applicability in multi-senor control system. Control logic and details of each module are reviewed in Sections IV–V. Section VI proposes clinical trials and cost valuation. Finally, conclusion is drawn in Section VII.

II. System Overview

As shown in Fig. 1, the PCCR based wheelchair consists of the sampling system, signal processing system, and interaction system.

In the sampling system, two eye trackers and one gyroscope are deployed to collect eye movements and wheelchair posture. The motion signals will be transformed into electrical signals and transferred to the microcomputer via the TTL-USB transformer. In the signal processing part, two microcomputers calculate received data in real-time. Next, the electrical signals generated by the microcomputer are converted to wheelchair control signals. In the interaction part, emergency call guarantees the user's safety in emergencies. Electrical motors provide the power supply and drive the whole system.

III. Sampling Module

A. Eye Structure & Imaging Principle

The eye serves as a special organ for light perception. The typical structure of the human eye[1] is shown in Fig. 2, based on which the gaze-tracking system is illustrated. As a sampling camera of the human body, retinal imaging is similar to convex lens imaging, i.e., the lens and retina are equivalent to a convex lens with a variable focal length and a light screen, respectively.

Visual perception starts at the light, which is emitted or reflected from an object and then enters our eyes. The cornea and lens focus and project light onto the photoreceptor layer of the cells located on the retina. The lens makes necessary adjustments to the focus of objects at different distances [5]. Meanwhile, the size of the pupil changes the amount of light reaching the retina which converts the

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[1] Source: Schematic diagram of the human eye en.svg - Wikimedia Commons. by Rhcastilhos and Jmarchn https://commons.wikimedia.org/w/index.php?curid=1597930 (accessed on Oct. 17, 2020 and licensed under CC BY-SA 3.0)

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optical signals into biological signals. The biological signals are transmitted to the visual processing area of the brain through the optic nerve and neuron pathways. To achieve visual tracking, we focus on the accurate recognitions on various eye movements (gaze, etc.) under the assumption of conscious and obvious visual attention. Due to physiological changes of the eyeball when gazing at one point, visual analysis algorithms and real-time computing technology with high precision and low latency are applied to obtain corresponding information.

B. Pupil Center and Cornea Reflection Technique

Fixation, composed of several movements (microsaccades, tremors, and drift) helping the eyes align with the target and avoid perceptual fading, is the most significant feature for processing recognitions. A critical factor to model fixation is gaze point information (GPI), which represents the spatial locations of the optic axis landing on the stimulus and its timestamps corresponding to its measurement. Next, the core technology of obtaining GPI for eye movement tracking is elaborated.

When light beams enter the human eyes, some of them will be reflected by the surface of different tissues inside the eyeball and the others will be refracted. With different brightness, light reflected via the cornea will be collected by the PCCR sensor [4]. After establishing light sources and cameras in different directions, a series of equations can be obtained to calculate the GPI. Due to the ethnic differences, our eye trackers (**Tobii Eye Tracker 5**) use two tracking methods to reduce measurement errors: dark pupil effect and bright pupil effect [7]. The sensors first send near-infrared rays and capture the motion of eyeballs to realize 3D head modeling under a certain movement pattern. After collecting the GPI, the signals are sent to the Intel NUC microcomputer via the USB interface. The image processing and system control programs installed in Software Development Kit (SDK) analyze the eye movements and generate control signals in real-time, respectively.

C. Multi-Sensor Control System

As shown in Fig. 4, multiple sensors are pre-installed for the wheelchair control system. One of the Dual Eye Trackers is used to track the eye movements to determine whether to go straight or not, the other collects the GPI to control whether to turn clockwise or counterclockwise. Meanwhile, Gyroscope sends a 3D pose signal and location information to Microcomputers.

After calculating and processing data from sensors, microcomputers transmit data stream to the Wi-Fi CPE which ensures access to the Internet. The microcomputers also give control signals to Electrical Motors to implement different moving behaviors. The wheelchair continuously feeds back the wheelchair status information (WSI) to the microcomputers, which forms a multi-sensor feedback control system.

IV. Control Module

A. Wheelchair Control Logic

The major problems concerning wheelchair movement safety are: 1) the difficulty in advancing and observing simultaneously; 2) potential view obstruction caused by peripherals. We optimize the design through

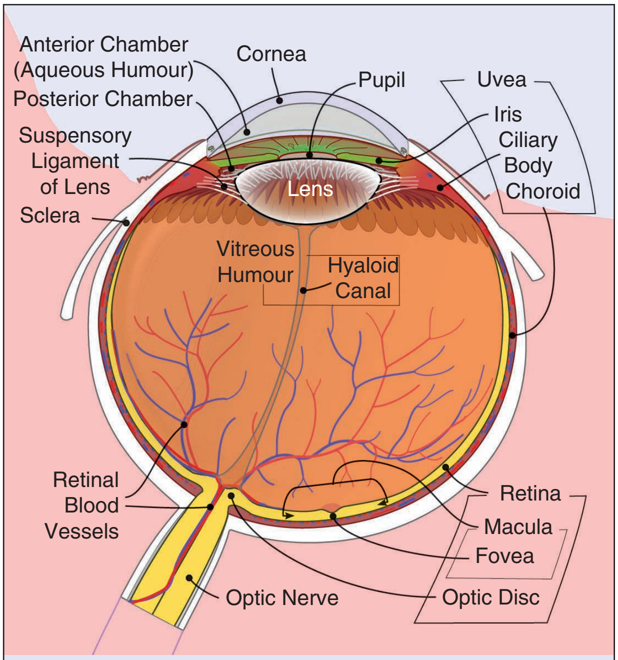

Figure 2. Schematic diagram of the human eye.

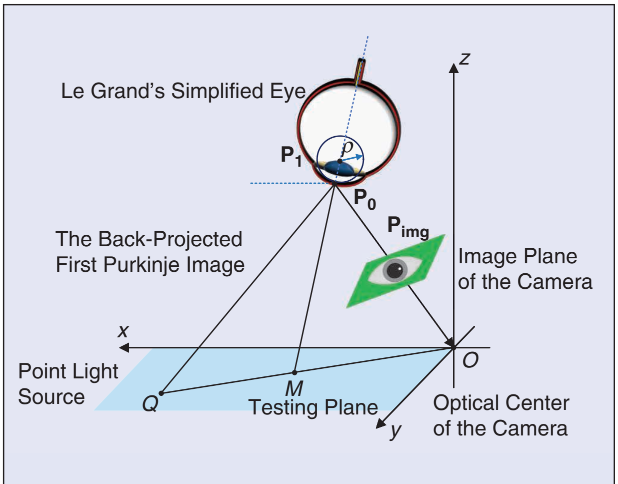

Figure 3. Geometric principles of PCCR technique [6].

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multiple experimental schemes. In the final version, an innovative control logic is proposed to solve the problem based on the monocular positioning algorithm. As shown in Fig. 5, the wheelchair advances when the user has only one eye open, and brakes automatically when both eyes are open or closed. To reduce chances of view obstruction, in the lower-left corner of the wheelchair, a physical screen detects the position of the focal length of user's eyes and assists the user to give the turning instructions: when a certain turning button has been gazed for more than 1s, the wheelchair will automatically turn in the corresponding direction.

For control signals, 11 signals fed into the engine are used to control the wheelchair motor, six of which are responsible for the starting and the speed, while the other five reflect direction adjustment. Three basic signals, VCC, GND and V_{erf} (standard voltage), and two control signals, S_A and S_B are included. Steering is realized when $V_{S_{A,B}} > V_{\text{erf}}$.

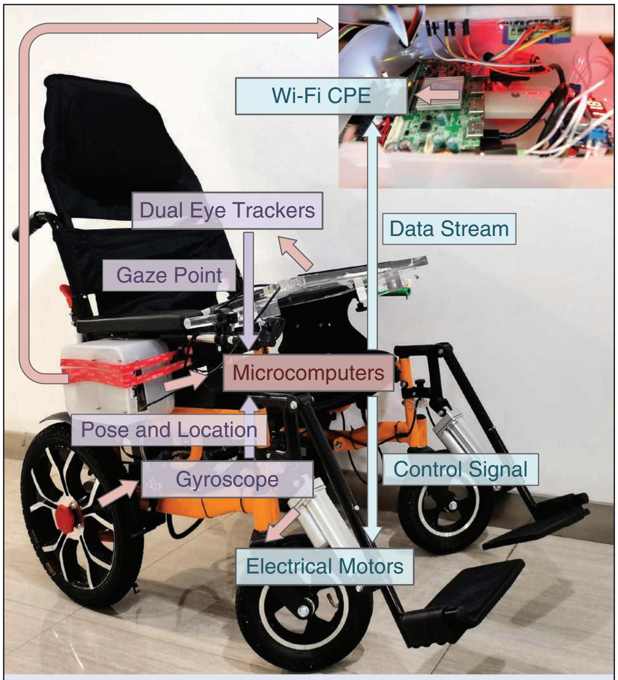

Figure 4. Overview of the multi-sensor control system.

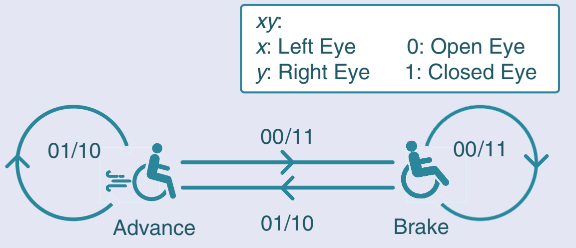

Figure 5. Flow chart of the wheelchair control logic.

B. SDK Secondary Development

In this subsection, we focus on the SDK secondary development, which contains two main parts:

- `Unity SDK`: To track the GPI, connect to the User Interface (UI) and communication module, and determine whether turning around.
- `Monocular SDK`: To identify monocular movements and determine whether to move forward.

According to the static class in `Tobii.Gaming` namespace, the `TobiiAPI` provides direct access to the functionality of the `Tobii Unity SDK` framework[2]. For further analysis of gaze focus detection, `GazePoint` and `HeadPose` from the sensors are obtained, which represent the user's gazing point on the screen, i.e., where the user's eye-gaze intersects with the screen plane, and the head position & rotation of the user's head, respectively. After accurate calibration and head modeling, the collected data are transmitted to the pre-loaded SDK program (guided by Subsection IV-A), which realizes intent analysis and robust control.

V. Auxiliary Peripheral Module

A. Mechanical Structure and Power Management

The mechanical structure is welded by high-strength stainless steel to protect users, which includes:

- A heavy chassis with a strong and wear-resistant structure, which is able to adjust the height to tailor the user's habits.
- An efficient motor providing strong power and a set of general current limiting resistance limiting the speed to guarantee safety.
- A 24V, 20Ah lithium-ion battery which ensures at least six hours of movement, completely satisfying outdoor activities.

B. Communication Module

A Wi-Fi Customer Premise Equipment (CPE) is deployed to provide wireless communication, which feeds back the WSI to the phone or computer in time. When the wheelchair rolls over, malfunctions, or meets an emergency, the system will call the preset contact, through VoIP telephony by Skype.

C. Display Module

The screen consists of two main parts:

- Virtual Screen: As the receiver of eye movements, the transparent screen in front of the user can be

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[2] The basic classes in C# are displayed on the website of Tobii as http://developer.tobiipro.com/unity/unity-sdk-reference-guide.html.

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perceived by the computer to avoid view blocked.

- Physical Screen: 4K Display for the specially-designed UI guides the user to steer and call.

VI. Preparation Before Mass Production

For mass production, clinical trials and cost valuation were conducted. Relative experiments on quadriplegia patients have been designed to warrant the wheelchair in the Neurology Department & Rehabilitation Center of the First People's Hospital of Shaoyang City, Hunan Province, China. The experiments have verified the functionalities of the designed wheelchair, though further improvements are required.

Production cost is another critical issue if the wheelchair will go to mass production. The detailed breakdown of the cost is listed in Table I for the demo version. The table shows that, the total cost of our wheelchair is $689.24, which is far less than the nursing cost. For mass production, further reduction of the cost is expected.

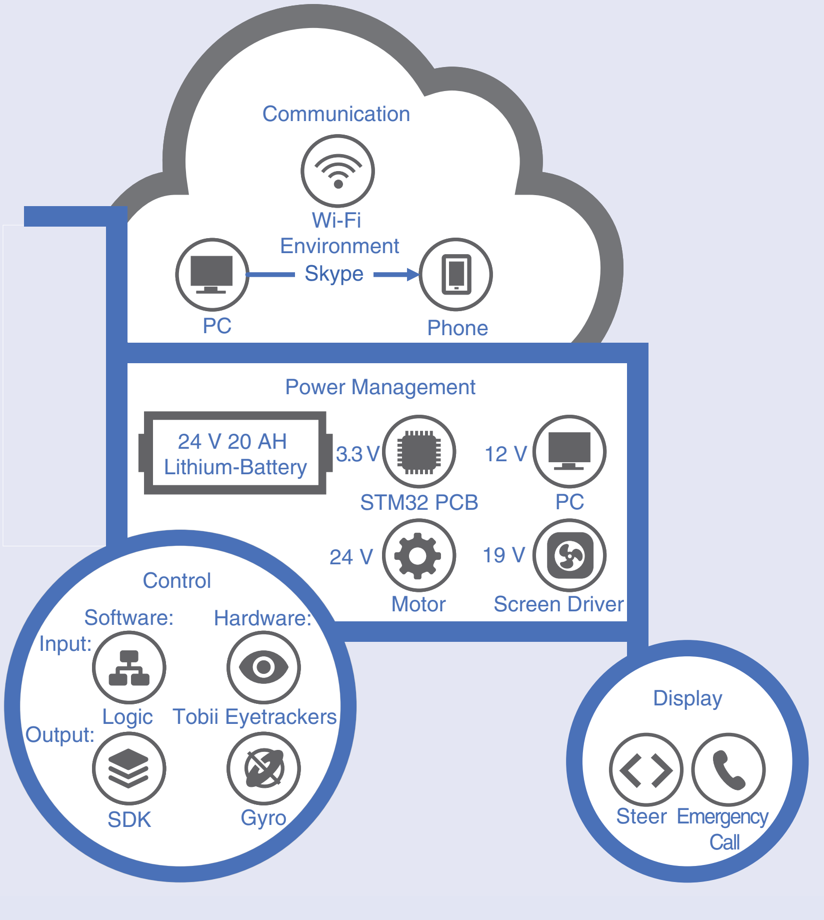

Figure 6. Schematic diagram of wheelchair function.

VII. Conclusion

Our team designs a PCCR based automatic wheelchair. As a pioneer in the field of visual control, we explore the possibility of combining visual recognition with intelligent devices for the disabled. With the easy-to-operate wheelchair, the patient can move freely within a specific range, which greatly relieves the pressure of nursing and finance in the rehabilitation of the disabled. According to the concept of *demand determines function*, the specific design ensures patients' safety. Effectiveness and low cost proved by clinical trials constitutes a market competitiveness. Further works will be directed towards the improvement of the wheelchair, the reduction of the production cost, and the real-life applications.

Table I.
Cost & Power Consumption.

Device	Cost/$	Power/W
Microcomputer	385.71	61.50
Eye Tracker	185.89	3.00
Screen	64.28	<10
Wi-Fi CPE	38.43	2.40
Gyroscope	9.29	0.01
Transformers	5.64	0.38 +
Total:	689.24	.75

Acknowledgment

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ProtonDx: Accurate, Rapid and Lab-Free Detection of SARS-CoV-2 and Other Respiratory Pathogens

Abstract

ProtonDx will provide a response to the COVID-19 pandemic by bringing nucleic-acid based molecular diagnostics to the palm of your hand. It will support the deployment of the Lacewing technology, which achieves accurate, rapid, handheld and low cost detection of SARS-CoV-2 and other respiratory infections. Results are synchronized to electronic health records and geotagged for real-time surveillance of disease progression. The device was designed for use at the point of need, in places such as pharmacies, schools and workplaces. Its unique approach combines standard semiconductor technology, advanced molecular biology and 3D printed microfluidics to match the performance of a bench-based instrument. Clinical trials are currently in progress at Imperial NHS Trust, London, UK which will lead to regulatory approvals and commercialization in the next few months.

I. Introduction

The emergence of SARS-CoV-2 in the late months of 2019 has triggered a new pandemic which has infected over 50 million people and caused over 1.5 million deaths at the time of writing this article, significantly straining health systems across the world. It has also caused drastic changes to our daily lives with country-wide lockdowns and travel restrictions across 2020, severely damaging the economy. Since the start of the pandemic, rapid testing has always been at the forefront of a path to recovery, while the research for a vaccine was ongoing. Governments have often set up a response strategy based on large-scale testing and contact tracing, with the intention to prevent the spread of the infection. These tests have been associated with numerous issues, among which inaccuracies and inaccessibility have appeared as the main challenges. In the UK, it is estimated that home tests require 4 days to receive results and patients need to travel just under 10 km on average to reach a testing site. New diagnostic technology is essential to provide efficient testing as a response to the COVID-19 pandemic.

There are mainly two types of tests available for COVID-19, viral and antibody tests. The viral tests are direct tests which are designed to detect the virus by targeting SARS-CoV-2 viral RNA or antigens, and therefore indicate current infection. On the other hand, antibody tests are indirect tests that measure established seroconversion to previous infection, or early seroconversion to ongoing infection. Figure 1 emphasizes the time relationship between diagnostic test and evolution of COVID-19 infection.

Great efforts have been made in order to develop rapid antigen test for SARS-CoV-2. However, the principal concerns are the false-negative rate due to inadequate limit of detection. The recommended test for diagnosis of SARS-CoV-2 infection involves detection of viral RNA using nucleic acid amplification tests, such as reverse transcription (RT)-PCR.

Our cutting-edge research at the interface of electronics, molecular biology and microfluidics at Imperial College London has enabled the development of

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